The document was prepared under a contract with the Office of Technology Assessment, Congress of the United States, for the assessment on Basic Research for the 1990s. The conclusions are those of the authors. The document does not necessarily reflect the analytical findings of the OTA, the Advisory Group, or the Technology Assessment Board.

# Science Indicators: Description or Prescription?

Susan Cozzens
Science and Technology Studies Department
Rensselaer Polytechnic Institute

Prepared under contract to the Office of Technology Assessment
July 1990

DRAFT – DO NOT CITE, QUOTE, OR REPRODUCE

J952-54

## Preface

In this report, I have been asked to provide a perspective on Science and Engineering Indicators. To make clear what that perspective is, I want to say a few words about where I stand--my connections to the Indicators project.

For five years, I was a policy analyst at the National Science Foundation. In my last year there, I worked half time with the Indicators staff preparing what became two chapters in Science and Engineering Indicators 1987. In this report, I have deliberately paid special attention to the perspective of staff--providing an insider's view. This view is important because in order to see clearly what the Indicators project is--part of my assignment in this report--one needs to understand it as those who produce it do. The staff viewpoint is also important in order to understand what SEI is likely to become if left on its present course. While a subset of the National Science Board first framed the project in the early 1970s, change since then has come largely from staff, as this report describes. Suggestions for indicators come from everywhere, but staff select those that will appear. No other group takes a strong hand in shaping the overall scope or detailed contents of the volume.

This report reflects more, however, than the perspective of a former insider. I am also a present outsider, with a particular stake in the kind of information SEI provides. I am part of the policy research community, a loose network of, on one hand, policy analysts who work across government gathering, stimulating, and summarizing information for policymakers, and on the other, an interdisciplinary collection of academic researchers with long-term research interests in the science and technology system. The Indicators project has always had strong connections to both branches of this network.

I have given the long-term perspective of the policy research community much weight in this report, even though that community is not SEI's intended audience. SEI is written for Congressional users. In contrast with policy researchers, many Congressional users are new or transient in science policy, have other important issues on their agendas, and do not read much. Particularly under these circumstances, it is essential that the information packaged conveniently for them in SEI be carefully selected and evaluated on the basis of the best current knowledge of both methods of data collection and the dynamics of science and technology. In other words, in order for SEI to be a concise, authoritative, accessible reference tool for Congress, it must rest on a whole community's knowledge base. Thus the relationship of the Indicators project to the policy research community is crucial to its effectiveness.

Already in this preface, I have referred both to the "Indicators project" and to the Science and Engineering Indicators volume itself (SEI). An important point that emerges from both staff and research community perspectives is that SEI is not just a product. It is also a process. The latter deserves more attention than it has been given in past assessments.

I should mention the limitations of the present report. My assignment from the Office of Technology Assessment was to produce a "statistical analysis" of SEI--a sort of "Indicators of Indicators" report. Within the limited time allotted to the project, I therefore chose to focus on the data themselves--on tables and graphs in the reports--rather than on text, which was not reviewed comprehensively. Furthermore, no resources were available for a user survey in connection with my project. While the views of a few knowledgeable users are reflected here, I sought such views mostly to gain perspective, and not to substitute for a more serious user survey. Finally, I know much more about fundamental research than about technology, and my analysis of the technology content of SEI may therefore be less accurate than my analysis of science.

Let me extend sincere thanks to the many people who discussed Indicators with me during the course of this project: SI staff, former staff, and chapter writers Jennifer Bond, Bob Brainard, Lawrence Burton, Don Buzzelli, Mike Crowley, Gerry Glaser, Carlos Kruytbosch, Larry Rausch, and Keith Wilkinson; NSF staff who have supervised the project in the past, Charlie Falk and Len Lederman; OECD Indicators staff members John Dryden, Gunnar Westholm, and Alison Young; participants in seminars at the University of Amsterdam and the Maison des Sciences de l'Homme, especially Stuart Blume and Rémi Barré; and other astute observers, John Campbell (GUIR), John Holmfeld (U.S. Congress), Al Teich (AAAS), and Wim van Deelen (EEC).

"The principal difficulty in your case," remarked Holmes in his didactic fashion, "lay in the fact of there being too much evidence. What was vital was overlaid and hidden by what was irrelevant. Of all the facts which were presented to us we had to pick just those which we deemed to be essential, and then piece them together in their order ... "

Sir Arthur Conan Doyle in
The Adventures of Sherlock Holmes

Executive Summary

## SCIENCE INDICATORS: DESCRIPTION OR PRESCRIPTION?

Since 1973, the National Science Board has issued a biennial report on the status of U.S. science and technology. First called Science Indicators (SI), its name was changed in 1987 to Science and Engineering Indicators (SEI). The volume is different from other Board reports in its focus on quantitative data describing various aspects of the scientific enterprise.

The founders of the Indicators project had high hopes for its impact. In particular, they wanted it to form an objective basis for assessing the results of federal funding for science, and to help focus efforts to synthesize overall understanding of how policy affects science and how science affects society.

The procedures and policies set up over the years to produce Science and Engineering Indicators make the achievement of these goals difficult. While SEI is an excellent statistical reference tool, its politically neutral text keeps it out of the business of assessment, and its encyclopedic size and organization transmit segmented information rather than a synthetic overview. At present, these tendencies are not counterbalanced with efforts to build an integrated model of the effects of policy on science and technology. Such a model is needed as a basis both for assessment and for the choice of key indicators.

Several options for changing this situation are proposed. The National Science Board could strengthen the planning process for SEI by appointing an advisory group that would devote its main efforts to integrating knowledge about science, technology, and policy and thereby influencing the development and choice of indicators. In order to overcome present NSF biases in the report, the advisory group should include representatives from other government agencies, from public interest groups, and from the academic community. To strengthen the assessment function of the project, Congress could ask a variety of agencies, as well as OSTP and OTA, to use SEI as a basis for producing policy statements of the sort the NSB has issued with the report in recent years. The implicit criteria of success used in these assessments could also inform the search for indicators. By widening the community involved in linking SEI to policy issues, these steps could help rejuvenate the project.

# Science Indicators:
# Description or Prescription?

Since 1973, the National Science Board has issued a biennial report on the status of U.S. science and technology. First called Science Indicators (SI), its name was changed in 1987 to Science and Engineering Indicators (SEI). The volume is different from other Board reports in its focus on quantitative data describing various aspects of the scientific enterprise.

This report provides a perspective on the Indicators series, and on the set of activities that produce it. I begin with my criteria for evaluation, which I have adopted from aspirations expressed in the early years of the project. Against these criteria, I compare the present process for producing the volume and its results. In the final two sections I point to some of the more important gaps in the current data, and make suggestions for modifying the current project in ways that will help it achieve the goals of its founders more fully.

## I. Aspirations

How should we assess Science and Engineering Indicators? Against what standards should it be measured? It is perhaps most appropriate to compare it with the aspirations its founders held for it.

Those aspirations shine through clearly in Congressional hearings held on the project in 1976. Testifying were Roger Heyns, the member of the National Science Board widely credited with initiating the Indicators project; Norman Hackerman, Board chairman during its first two appearances; and James Zumberge, then about to take over chairmanship of the NSB committee in charge of the project. Two other witnesses testified at a second hearing.

The time of these hearings was an important one in the development of the Indicators series. The 1972 volume had been assembled in the course of a few months, by one staff person working with an enthusiastic and energetic Board committee. After a stormy and uncertain process of approval both in the Science Board itself (who could not agree on how the numbers should be interpreted) and at the Office of Management and Budget and the White House (who thought it presented Administration policy in too unfavorable a light), the volume appeared amidst considerable fanfare in the science and general press.[1] An expanded 1974 volume had recently been issued at the time of the

hearings, also with extensive press coverage. The 1974 volume not only included more text, but also displayed a variety of efforts to develop new indicators. An indicators movement had well and truly begun.

At the hearings, Hackerman traced the origins of the volume to the Congressional mandate to the NSB with regard to its annual report, which was to focus on

> the status and health of science and its various disciplines (including) an assessment of such matters as national scientific resources ..., progress in selected areas of basic scientific research, and an indication of those aspects of such progress which might be applied to the needs of American society. [Hearings, p. 7]

According to Heyns, the Board committee developing the idea of the report had begun its work in 1970. By 1971 it had developed a list of seven purposes or functions the report should serve:

> 1. To detect and monitor significant developments and trends in the scientific enterprise, including international comparisons.
> 2. To evaluate their implications for the present and future status and health of science.
> 3. To provide the continuing and comprehensive appraisal of U.S. science.
> 4. To establish one new mechanism for guiding the Nation's science policy.
> 5. To encourage quantification of the common dimensions of science policy, leading to improvements in R&D policysetting within Federal agencies and other organizations.
> 6. To stimulate social scientists' interests in the methodology of this type of report as well as their interest in this important areas of public policy.
> 7. And finally, to provide a regular focus for the Board's annual reports. [Hearings, p. 10, emphasis added]

In the give and take of the hearings, two aspirations for the Indicators project are particularly evident. First is the hope that it would improve the ability to measure and evaluate the results of federally supported research and development, eventually to provide a basis for comparing the payoff of planned programs. This hope for assessment was, in fact, the stimulus for the hearings themselves.

Even in 1976, this task was beginning to be seen in terms of data alone; the shorthand for it was "developing output

indicators." "Output indicators" in the 1974 volume were based on publication and citation counts, patents, innovation counts, and relationships to economic indicators. (See Table 1.) But the founders' ambitions to trace the results of federal actions went well beyond the scope of this list. Several witnesses referred to the broader economic impacts of science and technology, including employment effects (positive and negative). Zumberge placed an even broader set of indicators first on the agenda for development: "indicators closely related to the societal applications of research and development outputs in energy, the environment, health care, law enforcement, transportation, and other areas." [Hearings, p. 21] Another witness reinforced this choice:

> If the report has some deficiencies--which it does--they must be attributed to a fundamental cause; namely, the lack of a clear understanding of the nature of the relationship between science and society. To some in the academic community good scientific research is essentially an end in itself. ... However, for the hard-pressed taxpayers of this country science must be more than a spectator sport for vicarious enjoyment. ... It is nice to know that the United States led the world in Nobel prizes from 1901 to 1974, but the average citizen is entitled to wonder whether he has any deeper stake in maintaining a strong scientific establishment. [hearings, p. 65]

A second, related aspiration evident in these hearings is the hope for synthesis. The founders of the Indicators project clearly believed that a continuing effort to refine and improve science indicators would eventually produce a better overall understanding of the interactions of policy with science, technology, economy, and society. This aspiration was expressed in several metaphors at the hearing. The chairman, Ray Thornton, compared the development of indicators to using stars to guide a ship. When he served as a ship's navigator in the Navy,

> ... we would take a star sighting and from that you get a line you could draw on the chart... That one line wasn't very useful to us. But if we could find a line from another star and cross it and then another one ... you could get a succession of lines that would define generally the areas where we might expect the ship to be ... [Hearings, p. 17]

In response, Heyns introduced the metaphor of the mosaic, "with increasing clarity of the image as a result of more data." But, he pointed out,

> we are still a long way from all the points on that screen.

> Without those, and maybe indefinitely without them, we have only qualitative judgments to make, almost like the difference between black and white and then making some guesses about color. [Hearings, p. 18]

Hackerman continued, "... there are more lines per inch. As we get smarter, the picture gets clearer." [hearings, p. 18]

Unfortunately, at the time of these hearings, the momentum behind these aspirations had already begun to wane. The easy progress had already been made.[2] Innovation in indicators by no means ground to a halt after this point. There has been a concerted effort by all involved to include some new types of data in each volume, and the volume has expanded in scope. (See analysis in the next section of this report.) But the character of the effort reveals an important deflection, from a focus on understanding to a focus on data, from assessment to description. Recent volumes have included overviews (a step toward synthesis) and statements by the National Science Board (a step toward assessment). But the very fact that these innovations are tacked on to the end of the production cycle for the volume, rather than being an integral part of its planning and production, reveals how far the Indicators project--while highly successful--has evolved away from the aspirations of its founders. The next section of this report describes that evolution.

## II. Evolution

### A. The production process

Beginning with the 1976 volume, the production of Science and Engineering Indicators has followed a relatively standard pattern.[3] For SI72 and SI76, Robert Brainard and his staff (for the second volume) reported directly to the National Science Board. After that time, the unit became part of NSF's Division of Science Resources Studies (SRS), a statistical service with responsibility for national science manpower and funding data. The Indicators unit has consisted of a head and (more or less) three chapter writers, each of whom plans and prepares one or two chapters. The personnel chapter has been prepared by another section of SRS; and the chapter on science education has been prepared in NSF's Directorate for Science Education.

In the first step in production, a staff member prepares a chapter outline, in consultation with the unit head. (In preparation for SEI87, the staff extensively re-outlined the book and reallocated chapter responsibilities, but this step is not a regular feature of production.) Chapter outlines are reviewed by SRS management, management in the Directorate for Scientific,

Technological, and International Affairs (where SRS is located), and by the Indicators committee of the National Science Board. Based on the final outline, the staff members prepare draft chapters, which go through review by the same bodies, as well as by outside experts, by other funding agencies, and by OMB and OSTP. In the 1970s, much of this review was sequential, making the total production process quite lengthy. In the 1980s, several steps were made simultaneous. Final updates in data series can be added as late as the summer before the volume appears, in January of even numbered years.

Surrounding this production cycle is the process through which indicators are developed and discovered. It has always been SRS policy to include some new indicators in every volume. The staff of the Indicators unit are therefore continually on the lookout for new data sources, and seek and receive suggestions from a wide range of sources. For instance, they are continually alerted to the needs of users through telephone calls--about 900 of them a year--for further information on what they have published. At least once in each production cycle, there is a conscious effort to talk with other analysts who work in the areas of each chapter.

Staff may find new data within surveys carried out in other parts of SRS, in other government or international agencies, or outside government. New staff members often bring fresh knowledge of outside data sources. The unit has also had a program of research to develop indicators in most years, but the amount of money available has declined, from $4-500 thousand per year in the 1970s, to about $350 thousand per year in the early 1980s, to a mere $30 in 1988 (all in current dollars). In addition, the Indicators unit has commissioned three special data series on a continuing basis:

(1) literature-based indicators (publication and citation counts);
(2) a public attitudes survey; and
(3) custom analysis of patent data from the U.S. system.

Some prominent features of this process combine to make Science and Engineering Indicators the kind of volume it is. First, there are many pressures to add indicators, and few to drop them. The pressures to add start with the historic emphasis on "new indicators." For example, the SRS Division Director for many years asked each chapter writer to come up with a list of ten new indicators for every volume, some available in the short term and others that would take longer to develop. Second are the interests of particular NSF constituencies, who want to see themselves represented in the book, either through new data

series or disaggregation of old series. Third is turnover in policy issues, which draw new attention to existing data and which sometimes help establish new data series, such as the data on academic instrumentation developed through the 1980s. Fourth is the breadth of the review process, where special interests are articulated and addressed.

In contrast, the pressures to eliminate indicators are minor. Indicators are often deleted when a new staff member takes over a chapter. Old indicators may not fit into the new conception of the chapter or may not meet the new staff member's criteria of quality. Indicators are sometimes dropped due to availability (a number of workforce indicators failed to appear in SI89 for this reason) or because of political sensitivities expressed in previous reviews (for example, the figures on R&D as a percent of the "relatively controllable" federal budget).

Occasionally, indicators have been added or removed in the review process over staff objections. Figures on patenting in energy technologies were removed this way by SRS management, and the data on Nobel Prizes were voted out by the Board committee on statistical grounds. Conversely, expenditure data by character of work (basic, applied, development) were reinserted in SEI89 at a late stage in the process. And at one point the Board committee reinstated the public attitudes survey after it had been eliminated from the SRS budget.

In a rare case, the "Advances in Science" chapter, a qualitative treatment of recent breakthroughs, was first added to the book in response to Board concerns, then removed with Board approval after staff cutbacks made it difficult to produce.

As for the review process, staff report that <u>most of the attention goes into text, not tables</u>, with major attention going to correcting or eliminating interpretation on the part of staff. This objective has historical roots that stretch back to the first volume. For SI72, the Indicators committee approved an interpretive text, but the full Board did not agree on the interpretation and sent the report back to the committee for redrafting. The final text has been described as "deadpan," a quality that has become characteristic of the volume. It is now Board policy that the data should speak for themselves. Even the Overview, which staff members point to as an attempt at analysis and interpretation, adopts the deadpan style and sticks closely to description of graphic displays. Under these circumstances, the main message of the document is carried in the selection of data itself. (See section III of this report.)

Finally, the production and review process are both structured around chapters. Along with the proliferation of indicators, this structure has made it harder and harder for anyone involved in the project to see the overall pattern in the mosaic. Two innovations in the 1980s have created opportunities to look for that pattern: the Overview, which is contained in the volume itself; and the NSB Statement that has been distributed along with SEI87 and SEI89. Each attempts to identify key indicators and create an overall portrait, the Overview in a descriptive way and the Statement in a way that more clearly identifies positive and negative factors, from the Board's viewpoint. But at this point, these exercises involve relatively few people, and neither of them feeds directly back into the planning process for the next volume, which is again left to staff judgment at the chapter level. The ambition of the Indicators pioneers to use the volume as a focus for synthesis and the development of an overall understanding of the S&T system thus finds limited expression in the current production process.

B. The results

Through this process, the Indicators volume has grown substantially over the years. In 1976, Roger Heyns reported to Congress that SI74 was 67% larger than SI72, although it contained only 50% more indicators--"reflecting," he said, "more interpretation of the data and an increased attention to some of their limitations." [Hearings, p. 12] SI76 was larger again. Starting with SI78, artificial constraints were placed on the size of the volume to keep it from growing further, and conscious effort went into justifying each indicator used. By the 1980s, these pressures had relaxed again. Table 2 shows the historical pattern in number of tables, which remained approximately 200 through SI85, and rose to about 250 in SEI87 and SEI89.

Table 3 lists eight broad categories of data that have appeared, and Table 4 shows the distribution of tables among data types. In most of the categories there is no clear trend up or down, with a few exceptions. Pipeline indicators appeared in the early volumes, declined in the middle volumes, then increased again the 1980s. Literacy indicators appeared infrequently before 1982 and have increased dramatically in the 1980s.

Connected to these changes, the sources of data have also shifted in the 1980s. Earlier, about half the data used by the Indicators unit came from surveys conducted in other parts of SRS. In the 1980s, however, only about 40% of the tables have been based on SRS data from outside the Indicators unit. In part this figure reflects the expansion of pipeline and literacy data,

both of which come primarily from outside NSF. But even in the personnel chapter, traditionally filled with results from SRS surveys, outside sources have increasingly appeared. This trend is clearly in the spirit of the Indicators pioneers; the mosaic is being filled in, without regard to source. It flies in the face, however, of a common myth that SEI is merely an overview of SRS data. The process of indicator search and selection is working, as it should, to make the volume much more than that.

Identifying turnover among indicators is difficult because of the enormous variety of data reported. A very crude analysis is attempted in Table 5. My interviews with staff indicate that the subcategories used in this table are still too broad to capture many of what they identify as "new indicators," which may appear in single tables or graphs, rather than grouped into sets like the ones I show here. The analysis is also sensitive to the way the sets have been defined; alternative groupings might show more, or less, change.

Nonetheless, even this broad-brush picture reveals a highly dynamic volume. According to this rough analysis, 79 distinct subcategories of data have appeared in the book over the years, about half in the original 1972 volume and about half added later. Fifteen of subcategories (19%) have been dropped, about half from the original set and about half from the expanded set. The total number of established subcategories has been stable since 1982 at about 65. A number of intermittent data types appear in the table, and other experimental indicators are hidden in the "other" lines. In terms of intermittent and "other" data, the 1987 and 1989 volumes show especially high levels of experimentation.

The categories of international and cross-sectoral contact, literacy, and pipeline show steady patterns of expansion in types of data. Resources, impacts and assessments, and scientific performance indicators have been largely stable, with some new types added. The economic performance indicators show high turnover--many categories added, and many dropped.

As shown in the comparison between Table 1 and Table 5, the new "output indicators" that Hackerman and Heyns reported with pride to Congress in 1976 have fared badly through the years, and there is little evidence of sustained progress in this direction. Under scientific performance, as noted above, the Nobel Prizes have disappeared. Publication and citation data are still the main forms of scientific performance data.[4] Of the eleven new types of economic performance data identified in Table 1, only two are clearly being continued, four were either never adopted regularly or were not presented in SEI89, and five have been

dropped (although staff report that an innovation survey is again being considered).

No new subcategories of data devoted to "the societal applications of research and development outputs in energy, the environment, health care, law enforcement, transportation, and other areas" (projected as top priority by Zumberge in 1976) have appeared. The public attitudes chapter remains the primary source of data on these topics.

By far the largest subcategories of indicators are the employment figures (in the workforce set) and the expenditure and obligations data (in resources). In these categories, subdivision--that is, a tendency to report finer and finer categories of the data--is an important factor in indicator change. For example, in the 1972 volume, the most disaggregated table reporting resource data showed 15 categories (fields of science; the most disaggregated table in the book showed geographic origins of Ph.D.s by state.) In contrast, the most disaggregated resource table in the 1989 volume, reporting industry support at the top 200 R&D-performing campuses, stretched over three pages. In the workforce data, cross-tabulations have also become more detailed, and with tables devoted to categories as fine as "Hispanic." As this example shows, the fine-grained categories often reflect timely policy interest. For example, industry spending for energy R&D was reported in the 1970s, disaggregated to the level of particular technologies.

This kind of quantitative analysis cannot capture internal improvements and change in the data, although in some subcategories these have been significant, for example:[5]

- the bibliometric indicators, which have gone from being estimated on the basis of journals to exact match by articles, and have gradually removed artifacts of measures

- the impacts and assessments and literacy measures collected in the public attitudes survey, which have shifted with policy issues and gone to an international comparative basis

- the operationalization of "high technology" in the trade figures, which has moved to a the more sophisticated DOC3 definition based on indirect as well as direct R&D intensity

- academic expenditures data, where reporting accuracy by survey respondents has improved.

C. Summary

In sum, the data in SEI have changed enormously, through internal improvement, accretion, and disaggregation. Together, these processes have produced a better quality, but more complex volume--again making the task of grasping the overall significance of the data (the founder's aspiration to synthesis) more difficult.

## III. Implicit Models

The processes of accretion and disaggregation describe SEI in an abstract sense; but what does the volume actually say? What is included and what is left out of the portrait of U.S. science and technology that has been so painstakingly assembled through the SEI production and review process?[6]

Most of what is in the book can be accounted for as the intersection of two factors: available data, and issues that were on the NSF policy horizon when the staff prepared the report. Staff unashamedly acknowledge that matters of interest to NSF get high priority for inclusion, and matters of interest to other agencies get lower priority. By implication, the generic issues of science and technology policy as a whole are not the focus.

But since there is no other indicators volume, prepared from any more general viewpoint, the "NSF view of the world" that is embodied in SEI gets wide circulation and attention. It is therefore worthwhile examining it, and suggesting issues and questions that might get more attention if the viewpoint of the volume were more general.

As the last section described, by NSF and NSB policy, the language of SEI is descriptive, not prescriptive or analytical. Any wording that draws attention to the perspective of the writer is systematically removed from the text. Chapter introductions therefore do not link the contents of one chapter to those of the other; even sections of chapters may not be clearly linked through text.[7] It thus seems that SEI <u>lacks</u> any overall, unifying model that makes sense of the connections among science, technology, economy, and society--all of which are presented in the book. If there is a model or set of assumptions, it is implicit in its structure, and in the selection of topics for description. Parts of the mosaic have been filled in, and others left blank.

A. The Input/output Paradigm

The volume certainly embodies an input/output paradigm--the assumption that science and technology are best described in terms of inputs, outputs, and impacts.[8] The input/output theme appears in the overall organization of the book, in which people flow into science from the general populace, do their research, and produce technological products that are then assessed. It is further reflected in smaller segments of the book, for example, the chapter on industry R&D, which begins with funding and people and moves through patent data to data on technologies themselves. The input/output paradigm is not just an organizational principle applied after indicators have been gathered. It also plays a generative role, through the long-term search for output and impact indicators.

The input/output paradigm conflicts, however, with SEI's goal of reporting on the health of research. Applied to this goal, the input/output paradigm implies that the more inputs, the healthier the system. Any analogy to biological health surely breaks down at this point, since organisms can have too much input (for humans, overeating leads in the short term to indigestion and in the long term to obesity), and the character of the inputs is important (toxins are to be avoided). In terms of outputs, the paradigm has overemphasized visible products emanating directly from science, at the expense of the less tangible embodiments of scientific and technical expertise in, for example, human capital. The input/output paradigm also skimps on attention to process, discussion of which is in scarce supply in the volume, and it distracts from the discussion of function--indicators of what research can do, rather than how much of it there is.

B. The Model of Research

Strangely, a portrait of research as an overall function in U.S. society is missing from SEI. What appears in its place is an extensive treatment of academic research, a bit of information on industrial basic research, and a smattering of input data on government research. Within academic research, biomedicine (the largest functional area) receives short shrift. Nonprofit institutions are almost entirely missing; SRS has not collected expenditure data in this sector for over a decade. So far, there is little on the interaction among the sectors in terms of research activities, and the data that do appear are not integrated into any overall picture. Despite the presence for a number of years of a chapter on basic research, and a chapter in SEI87 that spanned academic R&D and fundamental research, the treatment of research has reverted repeatedly to precisely the

scope of NSF's primary client group, namely, the university research community.

The lack of discussion of fundamental research in industry is particularly surprising given the current emphasis on science for competitiveness. By reporting the rising levels of university/industry interaction in various forms, the volume sends the message that university research has something to offer to industry--but what? This remains mysterious as long as the knowledge-generating and -utilizing activities of industry are left undescribed in a black input-output box. Likewise with government laboratories, where researchers are also collaborating with industry at higher rates than ever. The data themselves point to an ever more integrated research community; but only the academic portion of it receives significant attention in SEI.

True to the input/output paradigm, the question implicitly answered by the data that appear is "How much research is being done?" Left unanswered are a number of other questions, including several that reflect the aspirations of the Indicators pioneers.

- Is the research system as a whole meeting the goals outlined for it in the post-war agreements on Federal research support? Does it have sufficient vitality to serve as a resource for the nation as a whole?

- What goals for research are emerging in the U.S. and how is the research system as a whole responding to them?

- What is research like as a career? Is it still attractive to young people? Why or why not?

C. The Model of Technology

The discussion of technology is also partial. A linear model of the relationship between research and technology is certainly implicit. As mentioned, research is treated as an input to development in the industrial R&D chapter. In the chapter on markets for technology, high-technology trade is also taken as the ultimate output indicator for the S&T system. This linear model is convenient for NSF, since it provides an economic rationale for increasing funding to NSF-type research. For quite some time, however, it has been abandoned as a common assumption in policy circles. Because of the non-interpretive character of SEI, of course, it is not explicitly either endorsed or refuted there, but only used as an organizing principle.

Several important parts of an overall picture of technology

in America are missing in SEI's treatment. The emphasis is on the generation of ideas, as though this were the fuel in the engine of technological progress. This is surely too simple a view. There is virtually nothing presented on the process of technological choice within private or public firms that develop technology. Where are the indicators of firm strategy and of the interplay between firm know-how and technological development? Where are the technological alternatives that were abandoned? Where are the indicators of marketing and management knowledge, skills, and strength?

Likewise, there is little information about the people in firms who develop technology, their backgrounds, roles, and viewpoints. There is no portrait, for example, of engineering as a career or the careers of engineers. Questions of utilization of science and engineering talent are limited to whether people trained in these areas remained in science and engineering jobs, but there are other socially-useful ways of deploying their skills. Engineers as a professional group remain active in common professional organizations, whether or not they have moved into management. Is engineering as this kind of diversified career still attractive to young Americans? Why or why not?

Finally, SEI reports on markets for technology but not on how technologies are actually deployed after they are bought.[9] What kinds of technologies are moving into the workplaces of the U.S. and other industrial nations? Some figures on robots have been presented, but this is surely only a small part of the picture. The distribution of consumer technologies has not been reported, and there has been no global portrait that includes developing as well as developed countries. More attention to the deployment of technologies would allow for a closer link to the information that does appear in the volume on attitudes toward technology and the alienation of particular social groups from technical skills and careers.

D. The Model of the Science/technology Interface

The assumption of a linear model may have displaced attention from the actual structure of the science/technology interface in SEI. The set of indicators of cross-sectoral linkages has been growing, but it is largely limited to university/industry interaction. Again, the role of government laboratories and nonprofit research institutions, both of which have always concentrated in applied research, is notable by its absence. Several interesting indicators reported earlier were not used in SEI89.

The emphasis on interaction and flows of people in the

indicators that have appeared is promising. Interaction indicators do not assume a linear model, but leave conceptual space for the process of knowledge mandating from the user end.

E. The Model of Policy

Perhaps most striking of the omissions from SEI is the lack of attention to policy itself. Only the results of policy are seen, not the process. There is virtually no data about the Federal funding system--neither the "hard" data on applications, grants, and funding mechanisms, nor the "softer" indicators of researchers' attitudes toward the system. There is likewise no data about the role of scientists in government, or the increasing role of scientific and technical information in various areas of decisionmaking. In this regard, the public attitudes survey, which asks about funding priorities, reactions to public science programs, and attitudes toward regulation of science, is a bright spot in an otherwise dark corner of SEI's portrayal of science and technology. Yet even here, some results have received little attention, such as the low priority the public has consistently placed on defense, space, and basic research and the high priority it places on using research to solve the problems of health and the environment.

F. Summary

In SEI, the pattern of filling in the matrix describing science and technology clearly reflects an "NSF view of the world." Inventive activity gets attention; the impacts of inventions are left out. The needs of science are portrayed, but the tradeoffs that science policymakers face are not present. SEI is a quantitative portrait, but this does not make it "objective." The mosaic-maker is constrained by data, but the result is nonetheless a self-study, created against a carefully chosen background.

In assessing the volume against the ambitions of its founders, we again find that it falls short. Heyns and Hackerman in 1976 portrayed a generic document, that described science and technology as a whole system, interacting with both industry and society. What has developed is more closely tied to NSF's specific interests.

But this is not the only challenge posed to the current volume by the aspirations of its founders. Many of the topics mentioned above are unlikely ever to be located for inclusion in SEI through a data-limited process that focuses on immediate policy concerns. They are much more likely to surface, however, in the kind of effort to develop an overall model of the system

and how policy affects it that the founders described to Congress in 1976. Qualitative knowledge may need to precede quantitative knowledge, in order to point to the areas where data is needed most.

IV. Options

There is general consensus that Science and Engineering Indicators is a success. The signs of success are varied: its use as the model for indicators projects in other countries; the large number of information calls its staff handle each year; the extensive coverage each volume still receives in the science press. If SEI falls short of the ambitions expressed for it by its founders, the fault may lie on the side of the founders, who perhaps set their sights too high.

In fact, the kind of success SEI has experienced was not entirely foreseen in 1971. The volume has turned out to be a success as a statistical reference tool, rather than as an analytic report. The search process for indicators is highly effective in gathering an important set of data into the book, more comprehensively than in any other document produced in U.S. science policy. Many users may never have occasion to notice that the text is disjointed and treats topics only partially, if they are entering the book through the appendix tables, through graphic displays, or through highlights and the Overview, and using only the small portions relevant to their immediate questions. For these users, the volume serves as the equivalent of an encyclopedia or almanac of science policy, and any change in the direction of more assessment or more synthesis--á la the ambitions of its founders--might threaten that portion of its success that rests on this important reference function.

There are a number of modifications, however, that could be made to the Indicators process that would bring it closer to the original Board concept while retaining the strengths of the current volume.

First, the oversight function now performed by an NSB subcommittee could be delegated by NSB to a more broadly composed advisory group, with stronger functions than the subcommittee now assumes.

In order to overcome the NSF/university research bias in the volume, the new advisory group should include representatives or nominees from other research-funding agencies; from agencies more concerned with science and technology in action, such as the Departments of Labor and Commerce; and from public interest groups concerned with science and technology issues. The

advisory group should also include some academic policy researchers, to strengthen the link with the specialist communities developing and using models of science and technology. Its head should of course show Roger Heyns's level of enthusiasm for science and technology indicators.

The main function of this advisory group should be to develop the model of science, technology, and policy that underlies the report. It should therefore give its main attention to planning, not oversight, and in particular to the assessment and synthesis activities envisioned by the Indicators pioneers. Debate on assessment and synthesis should be used to articulate explicitly the criteria for choice of indicators. As with the NSB in 1973, this new group may not come to consensus on how to interpret the indicators, or which are the most important. But its true function would be to open up the process of discussion of these issues again with a broader community. In this regard, occasional open conferences, like those held in Paris by the OECD indicators group, would encourage the development of the relevant knowledge base in the United States.

Like the Science Board subcommittee, the new advisory group should have the final say, over NSF management, on what is included in the report, so that like the subcommittee, it can stand behind the staff when they want to push beyond the conservative limits that the political process within a funding agency might otherwise impose.

Also in the spirit of opening the process of indicator development, SRS should consider <u>making staff assignments to the Indicators project on a temporary basis</u> only. Task groups could be formed ad hoc for each volume, perhaps including analysts from other parts of NSF, other agencies or groups, or academic institutions, on a temporary basis. In this new form of organization, cumulative knowledge about what the project is and how the indicators are chosen would not reside in staff alone, but in a larger network that includes the advisory group and the policy research community it draws into the Indicators process.

The current function of the volume as a statistical reference tool fits comfortably with the mission of SRS as a whole. In particular, the volume has benefitted from the high standards of data quality maintained by the SRS staff. The reference function of the volume could be strengthened by <u>reducing the amount of text in the volume, or by reorganizing it into true alphabetic encyclopedia form</u>. By reducing text, the process of reviewing the report could perhaps be streamlined, since most of the energy of the review process goes there. A volume consisting of Overview, highlights, graphic displays with

captions, and appendix tables would probably serve a large part of the function of the current volume, but be simpler and quicker to produce.

In order to strengthen the assessment and synthesis functions of the Indicators project, several complementary types of Indicators reports could be produced. First, an independent Indicators report could be prepared by a group outside government. This report would focus on analyzing the available information, qualitative or quantitative, on the state of U.S. science and technology and their impacts on society, based on the best available knowledge in the academic disciplines that contribute to science policy. In this way, it would concentrate on functions that are kept to a minimum in the current volume. The process of producing the report would encourage synthesis, and the task could rotate among a number of institutions with different kinds of interests in science and technology.

In addition, based on the biennial Indicators report, the governing boards of other federal agencies (both research funding and those concerned with science in action) should consider preparing their own Statements on the status of U.S. science and technology in parallel with the NSB's Statement, as should public interest groups. This process would soon make clear a number of gaps in the coverage of the volume that make it fall short of the comprehensive viewpoint envisioned by its founders. Finally, the Office of Science and Technology Policy and the Office of Technology Assessment, from their positions as overview agencies, could also prepare brief Statements on the status of U.S. science and technology based on the Indicators report. Together, these statements would begin to take up the task of assessment that Congress has wanted for so long from SEI. As concepts and criteria for assessment are articulated in this process, a new approach to the problem of performance indicators might be developed from this base.

In sum, the pioneering spirit of the early Indicators volumes needs to be recaptured if the project is to produce the kind of information base for policy making that its founders envisioned. An expanded effort to plan, discuss, and use the current volume could provide the necessary stimulation.

## Notes

1. As reported by Robert Brainard, the staff member who prepared the first report.

2. Robert W. Brainard, interview with Susan Cozzens, April 1990. Zumberge, the incoming chair of the Board committee, foreshadowed what was to come:

> My plan for the next Indicators report is to try to retain as much as possible those indicators in the 1974 edition that have proven to be useful and simply to add another 2 years of information. I would opine that perhaps for the next Indicators report there will not be the same amount of change as one sees between the 1972 and the 1974 issues. I think there is some benefit in not having a tremendously changed edition each time. [Hearings, p. 24]

3. This process may change for the first time for SEI91. Plans were still being formulated as this report was prepared.

4. The bibliometric database has added more to the categories of international and cross-sectoral contacts than it has to measures of scientific performance.

5. These examples were provided by staff, except the bibliometrics case which I know from my work for the Indicators unit as bibliometrics consultant.

6. Appendix A, a summary of trends since the 1960s, gives a feeling for the sorts of insights the data provide.

7. This point was brought home to me sharply in an interview with a new staff member, who reported that he could found the chapter as it had been written before "disjointed." That is, even to this expert, the underlying logic of the presentation was not clear.

8. Outputs are the immediate products of research or invention, such as papers and patents. Impacts are the longer term results of research and invention for economy and society. Charles Falk claims credit for introducing the distinction.

9. Staff report that use of indicators of the deployment of technologies in manufacturing is under consideration for SEI91.

## Reference

Hearings. 1976. "Measuring and Evaluating the Results of Federally Supported Research and Development. Science Output Indicators--Part I. Special Oversight Hearings." Hearings before the Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology, U.S. House of Representatives. Ninety-fourth Congress, Second Session. May 19 and 26, 1976. Washington, DC: U.S. Government Printing Office.

Table 1

**Output Indicators Included in SI74**
as reported to Congress, 19 May 1976

Output Indicators Based on Literature Counts
- National Origins of Scientific Literature
- Output of Scientific Research Literature

Output Indicators Based on Citation Counts
- International Scientific Literature
- Literature Citations
- Basic Research and Technology

Output Indicators Based on Patent Counts
- The Patent Balance
- Foreign Origin Patents by Product Area
- Patented Inventions

Output Indicators Based on Innovation Counts
- International Trends in Technological Innovation
- Time Between Invention and Innovation
- Innovation and Company Size
- Innovation and R&D Intensity
- Industrial Research Magazine "IR-100" Awards
- "Radicalness" of Innovations
- Research and Innovation

Output Indicators Related to Economic Indicators
- Technical "Know-How"
- Balance of Trade in R&D Intensive Products
- Productivity

Miscellaneous Output Indicators
- Participation in Scientific Congresses
- Nobel Prizes in Science

Source: "Measuring and Evaluating the Results of Federally Supported Research and Development. Science Output Indicators--Part I. Special Oversight Hearings." Hearings before the Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology, U.S. House of Representatives. Ninety-fourth Congress, Second Session. May 19 and 26, 1976. Washington, DC: U.S. Government Printing Office, 1976. Pages 3-5. The list was prepared by NSF staff for these hearings.

Table 2

**Growth of Science and Engineering Indicators**

| Volume | Number of Tables | Pages of text |
|---|---|---|
| 1972 | 112 | 93 |
| 1974 | 173 | 151 |
| 1976 | 188 | 182 |
| 1978 | 141 | 138 |
| 1980 | 207 | 205 |
| 1982 | 213 | 189 |
| 1985 | 178 | 180 |
| 1987 | 249 | 166 |
| 1989 | 258 | 177 |

Table 3

**Categories of Indicators**

INTERNATIONAL CONTACTS.
Cross-national citations and coauthorships, publishing in foreign journals, participation in international scientific congresses, employment plans of foreign students, U.S. students and academics going abroad

CROSS-SECTORAL LINKAGES
Citations from patents to the scientific literature, cross-sectoral coauthorship, cross-sectoral citation, mobility between sectors, university patenting

ECONOMIC PERFORMANCE
Patents, trade and trade balances, productivity measures, global investments, innovation indicators, high-technology business sector, venture capital

IMPACTS AND ASSESSMENTS
Public views on allocation of resources for science, judgments of benefit and harm from science and technology, prestige of scientists, expectations of scientific advances and problems caused by science, issues of control and restraint of science, differences between the attentive and general public

LITERACY
Enrollments in science and mathematics, course content and testing requirements, achievement and test scores, teacher characteristics and activities, public understanding of scientific concepts, public use of technologies, student attitudes toward science and technology

PIPELINE
College and graduate school enrollments in science, engineering, and mathematics, degrees, test scores and other quality measures, preferences and plans of high school and college students, sources of student support

RESOURCES
Expenditures and obligations, special research resources, instrumentation and facilities

SCIENTIFIC PERFORMANCE
Publication and citation counts, Nobel Prizes

WORKFORCE
The science and engineering workforce: Comparative measures, demographic characteristics, career variables, sources of support, technicians, stock and flow analysis

Table 4

## Trends in Distribution of Indicators among Categories

| Year | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Number of Tables | | | | | |
| Resources | 38 | 63 | 57 | 58 | 41 | 52 | 49 | 47 | 60 | 465 |
| Workforce | 18 | 37 | 35 | 35 | 54 | 37 | 29 | 38 | 30 | 313 |
| Economic Performance | 9 | 31 | 47 | 22 | 40 | 37 | 20 | 35 | 45 | 286 |
| Impacts and Assessments | 21 | 14 | 21 | | 39 | 35 | 19 | 29 | 18 | 196 |
| Pipeline | 23 | 13 | 9 | 3 | 1 | 14 | 22 | 29 | 26 | 140 |
| Literacy | 1 | | | | 1 | 4 | 14 | 46 | 54 | 120 |
| Scientific Performance | 2 | 10 | 11 | 10 | 11 | 15 | 7 | 4 | 7 | 77 |
| International Contacts | | 2 | 8 | 10 | 11 | 11 | 11 | 9 | 8 | 70 |
| Cross-sectoral Contacts | | 3 | | 3 | 8 | 7 | 6 | 12 | 7 | 46 |
| Non-indicators | | | | | 1 | 1 | 1 | | 3 | 6 |
| TOTAL | 112 | 173 | 188 | 141 | 207 | 213 | 178 | 249 | 258 | 1719 |
| | | | | | Percent of Total | | | | | |
| Resources | 34 | 36 | 30 | 41 | 20 | 24 | 28 | 19 | 23 | 27 |
| Workforce | 16 | 21 | 19 | 25 | 26 | 17 | 16 | 15 | 12 | 18 |
| Economic Performance | 8 | 18 | 25 | 16 | 19 | 17 | 11 | 14 | 17 | 17 |
| Impacts and Assessments | 19 | 8 | 11 | 0 | 19 | 16 | 11 | 12 | 7 | 11 |
| Pipeline | 21 | 8 | 5 | 2 | 0 | 7 | 12 | 12 | 10 | 8 |
| Literacy | 1 | 0 | 0 | 0 | 0 | 2 | 8 | 18 | 21 | 7 |
| Scientific Performance | 2 | 6 | 6 | 7 | 5 | 7 | 4 | 2 | 3 | 4 |
| International Contacts | 0 | 1 | 4 | 7 | 5 | 5 | 6 | 4 | 3 | 4 |
| Cross-sectoral Contacts | 0 | 2 | 0 | 2 | 4 | 3 | 3 | 5 | 3 | 3 |
| Non-indicators | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| TOTAL | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

Each table, text or appendix, is counted once.

Table 5

**Addition and Deletion of Subcategories of Indicators**

INTERNATIONAL CONTACTS

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cross-national citations | | X | X | | X | X | X | X | X | A/C |
| Publishing in foreign journals | | | X | X | X | X | X | | | A/D |
| Cross-national co-authorships | | | X | X | X | X | X | X | X | A/C |
| Participation in scientific congresses | X | X | X | X | | | | | | D |
| Foreign students/ employment in US | | | X | X | X | X | X | X | X | A/C |
| US students/academics going abroad | | | | | | | X | X | | A/* |
| Others | | | | X | X | X | | | | |

CROSS-SECTORAL LINKAGES

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Citations from patents to published literature | | X | | | | | | X | | - |
| Co-authorship | | | | X | X | X | X | X | X | A/C |
| Cross-citation | | | | | X | X | | X | X | A/C |
| Flows of people | | | | | | X | X | X | | A/* |
| University patenting | | | | | | | | X | X | A/C |
| Others | | | | | | | X | X | X | |

---

"A"=Added (appeared in two consecutive volumes)
"D"=Dropped (failed to appear in two consecutive volumes)
"-"=Appeared, but not in two consecutive volumes
"*"=Failed to appear, but only in SEI89

Addition and Deletion of Subcategories of Indicators

ECONOMIC PERFORMANCE

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Patents | | | | | | | | | | |
| US patenting elsewhere | X | X | X | X | | X | X | | | D |
| Patenting in US | | X | X | X | X | X | X | X | X | A/C |
| Citations among patents | | | | | | X | | | X | - |
| Trade/trade balances | | | | | | | | | | |
| Balance of payments | X | X | X | | | | | | | D |
| Payments and receipts | X | X | X | X | X | X | X | X | X | C |
| Transfer of innovations | | | X | | X | X | | X | | A/* |
| Domestic markets | | | | | | | | | X | - |
| Global markets | | | | | | | | | X | - |
| Other | | | | X | X | X | X | X | X | |
| Productivity | | | | | | | | | | |
| Productivity measures | X | X | X | X | X | X | | | | D |
| Unit labor costs | X | X | X | | X | | | | | D |
| GDP per employee | | X | X | X | X | | | | | A/D |
| Capital investments | | | | X | X | | | | | A/D |
| GNP/GDP | | | | | | X | X | | X | A/C |
| Global investments | | | | | | | | | | |
| US investment abroad | | | | X | X | X | X | X | X | A/C |
| in R&D activities | | | | X | X | | | | | A/D |
| Foreign investment in US | | | | | X | | | X | | - |
| Innovation indicators | | | | | | | | | | |
| Unit innovation study | | X | X | | | | | | | A/D |
| IR100s | | X | | | | | | | | - |
| Technology performance indicators | | | | | X | | | | | - |
| New high-tech products | | | | | | X | X | X | | A/* |
| Other | | X | | | | | | X | | |
| High-tech business sector | | | | | | | | | | |
| Firm formation indicators | | | | | | X | X | X | | A/* |
| Venture capital | | | | | | X | X | X | X | A/C |
| Employment by firm types | | | | | | | | X | X | A/C |
| Other | | | | | | X | X | | X | |
| Others | | | | | X | X | | | X | |

---

"A"=Added (appeared in two consecutive volumes)
"D"=Dropped (failed to appear in two consecutive volumes)
"-"=Appeared, but not in two consecutive volumes
"*"=Failed to appear, but only in SEI89

Addition and Deletion of Subcategories of Indicators

IMPACTS AND ASSESSMENTS

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Allocation of resources/ interest in science policy | X | X | X | X | X | X | X | X | X | C |
| Benefit/harm judgments | X | X | X | X | X | X | X | X | X | C |
| Prestige/confidence/ international standing | X | X | X | X | X | X | X | X | X | C |
| Expectations for advances/problems | X | X | X | X | X | X | X | X | X | C |
| Control/restraint issues | | X | X | X | X | X | X | X | X | A/C |
| Attentive public | | | | | X | X | X | | | A/D |
| Others | X | | | | | X | | | | |

LITERACY

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Enrollments | X | | | | | | X | X | | A/* |
| Test scores | | | | | X | | X | X | X | A/C |
| Teacher characteristics/ activities | | | | | | | X | X | X | A/C |
| Public understanding | | | | | | X | X | X | X | A/C |
| Public use of technologies/information | | | | | | | | X | | - |
| Course content/ testing requirements | | | | | | X | | X | X | A/C |
| Student attitudes | | | | | | | | X | | - |

"A"=Added (appeared in two consecutive volumes)
"D"=Dropped (failed to appear in two consecutive volumes)
"-"=Appeared, but not in two consecutive volumes
"*"=Failed to appear, but only in SEI89

Addition and Deletion of Subcategories of Indicators

PIPELINE

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Enrollments | X | X | X | | | X | X | X | X | C |
| Institutions | X | | | | X | X | | X | | A/* |
| Degrees | X | X | X | X | X | X | X | X | X | C |
| Geographic/ institutional origins | X | | | | | | | X | | - |
| Test scores/ quality measures | | | | X | | X | X | X | X | A/* |
| Preferences/plans | | X | X | | | X | X | X | X | A/C |
| Support | | | | | | | X | X | X | A/C |
| Other | X | | | | | | X | X | | |

RESOURCES

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Institutional rankings | X | X | X | X | | X | X | X | X | C |
| Special facilities/ resources | X | X | X | | | X | X | X | X | C |
| Expenditures | X | X | X | X | X | X | X | X | X | C |
| Federal obligations | X | X | X | X | X | X | X | X | X | C |
| Grants budget categories | X | X | | X | | | | | | D |
| R&D intensiveness (industry groups) | X | X | X | X | | | | | | D |
| Equipment inventory | | | | | | X | X | X | X | A/C |
| Research facilities | | | | | | | | X | | - |
| Other | X | | | | X | | X | | X | |

SCIENTIFIC PERFORMANCE

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Publication counts | X | X | X | X | X | X | X | X | X | C |
| Citation ratios | X | X | X | X | X | X | X | X | X | C |
| Nobel Prizes and others | | X | X | | | X | | | | A/D |
| Dissertations | | | | | | X | | | | - |

---

"A"=Added (appeared in two consecutive volumes)
"D"=Dropped (failed to appear in two consecutive volumes)
"-"=Appeared, but not in two consecutive volumes
"*"=Failed to appear, but only in SEI89

Addition and Deletion of Subcategories of Indicators

WORKFORCE

| | 72 | 74 | 76 | 78 | 80 | 82 | 85 | 87 | 89 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Relative measures | | | | | | | | | | |
| Per gen. workforce | X | | | X | X | X | X | X | X | C |
| Int'l comparisons | | X | X | X | | X | X | X | X | A/C |
| Other | X | | | | X | | | | X | |
| Demographics | | | | | | | | | | |
| Sector | X | X | X | X | X | X | X | X | X | C |
| Age | X | X | X | X | X | X | X | X | X | C |
| Immigrant status | X | X | X | X | | | X | | | D |
| Women | | X | X | X | X | X | X | X | X | A/C |
| Minorities | | X | X | | X | | X | X | X | A/C |
| Career variables | | | | | | | | | | |
| Transition into workforce | X | | | X | X | X | | X | X | C |
| Salaries | | | | X | X | X | X | | | A/D |
| Activities | X | X | X | X | X | X | X | X | X | C |
| Retention rates | | | | X | | | | X | | - |
| Un/underemployment | X | X | X | X | X | X | X | X | X | C |
| Support | | X | X | X | | | | X | | A/* |
| Technicians | | | | | | X | | X | | - |
| Postdocs/research asst. | | X | | | | | | | | - |
| Stock and flow analysis | | | | | | | | | X | - |

---

"A"=Added (appeared in two consecutive volumes)
"D"=Dropped (failed to appear in two consecutive volumes)
"-"=Appeared, but not in two consecutive volumes
"*"=Failed to appear, but only in SEI89

APPENDIX A

Interim Report
Task Three, Contract #N3-2315.0
SCIENCE INDICATORS: DESCRIPTION OR PRESCRIPTION?

Susan E. Cozzens, 28 June 1990

**What do the indicators show about**

**- the structure of the scientific enterprise and the place of basic research in it?**

**- significant changes since the 1960s in U.S. R&D, and their causes?**

To answer these questions briefly, one must select from among the many specific kinds of data reported in Science and Engineering Indicators. To begin that selection, I focused on the Overview and chapter highlights of SEI89, and went back to earlier volumes as necessary to find baselines for comparison with the most recent indicators. This brief discussion thus condenses even further an already condensed version of the information in SEI.

**In summary**, since 1960, U.S. industry has invested steadily in R&D, across a widening range of industries. But this investment has not been reflected in success in the marketplace, where the U.S. has lost market shares, both domestically and worldwide, in high technology products.

Over the same time period, academic R&D has grown in proportion to the overall national effort, and academic institutions have increased their links to other U.S. and foreign institutions. The excellence of U.S. academic research can be documented at least through the early 1980s.

In part due to the cutbacks in federal support for applied research during the 1980s, government research laboratories have not kept pace with the growth in the industrial and academic sectors.

U.S. students have poor technical skills in science and mathematics by international standards, and the U.S. public is no more knowledgeable about facts that scientists consider elementary than the publics of other nations. The public places hope in science and technology to solve the problems of modern society, but is less confident in the ability of science and technology to provide solutions than they were before the great expansion of U.S. scientific capability began. The public would like to see priorities in funding re-directed toward improving health and the environment, and away from basic research, defense, and space.

**Research and Development: Components**

1. Research and development are growing functions in the United States.

- Growth in R&D spending has gone through cycles, with one growth spurt in the 1960s and another in the 1980s. [SEI89, p. 3]

- Employment of scientists and engineers went through similar cycles. It was high in the mid-1960s, dropped until 1975, and has been growing since then. [SEI89, p. 5]

2. R&D is supported at about equal levels by the federal government and by private industry. Since 1960, the balance has shifted toward private industry.

- In 1961, private industry provided 33% of the funds and the federal government 65%. [SI72, p. 109]

- In 1989, industry provided an estimated 48%, and the federal government an estimated 47%. [SEI89, p. 88]

3. The three major performers of R&D are industry, government laboratories, and academic institutions. Academic institutions have increased their share of expenditures since 1960.

| | 1960 | 1989 |
|---|---|---|
| Industry | 78% | 72% |
| Federal government | 13% | 11% |
| Academic | 5% | 11% |
| Univ-assoc. FFRDCs | 3% | 4% |

[SI74, p. 174 and SEI89, p. 88; 1989 numbers estimated]

**Industrial R&D/ Applied Research and Development**

**1. Industry does most applied research and development, and has for some time.**

**- In 1960 it spent 87% of the nation's development funds and in 1989 it spent 85%.**

**- The comparable figures for applied research are 41% in 1960 and 53% in 1989.**

**[SEI89, p. 266 and 268; 1989 figures estimated]**

2. Over the long term, federal support for industrial R&D has remained about even, in constant dollar terms, while company support has grown. [SEI89, p. 130] As a result, industry now supports over half of its development efforts from its own funds (62% in 1989), in contrast with 1960, when the federal government supported 64% of the development work in industry. [SEI89, p. 266]

3. Industrial R&D is concentrated in a few industries (five industries accounted for 67% of the R&D spending in 1986).

- But it is less concentrated now than in 1970, when the same five industries accounted for 81%.

- Growth in R&D spending has been especially rapid in the chemicals and electrical equipment industries.

[SEI89, p. 131 and 352; data for 1986 are preliminary]

4. Part of the concentration of R&D in 1970 was due to heavy federal spending in the aircraft and missile industry, where 73% of the R&D funds still come from the federal government. But R&D growth in that industry has been relatively slow. The increase in R&D spending in the aircraft industry between 1970 and 1986 was about 15% (in constant dollars) as compared with 65% overall. [SEI89, p. 131 and 352; data for 1986 are preliminary]

5. The amount of R&D performed in industry grew faster in France, the U.K., and Japan than in the U.S. between 1970 and 1986, but more slowly in West Germany. Over this period, government funding of industrial R&D grew faster than funding by industrial firms themselves in West Germany and Japan; company funding grew faster than government funding in France, the U.K., and the U.S. [SEI89, p. 349]

6. In the U.S. patent system, the number of patents issued to U.S. inventors declined from 1970 to 1983, but has been growing since then. The number granted to foreign inventors has been growing even faster, however. [SEI89, 134]

7. The U.S. share of the world market for high technology goods declined from 51% in 1970 to 42% in 1986. Its share of the domestic market has also eroded; imports have increased from 5% in 1970 to 18% in 1986. [SEI89, p. 148]

8. The U.S. balance of trade in high technology products went negative for the first time in 1986, and recovered only slightly in 1987. [SEI89, p. 148]

**Academic R&D/ Basic Research**

1. Basic research as a whole has grown since 1960 as a percent of overall R&D spending, from 9% to 14%. [SEI89, p. 264 and 270]

2. Universities and colleges (along with their affiliated FFRDCs) perform more basic research than any other sector--63% in 1989. In 1960 they spent only 44% of the basic research funds. The share of basic research performed in industry has declined since 1960, from 31% to 17%. [SEI89, P. 270-71]

3. In the late 1980s, university research was growing faster than any other part of the R&D system. The growth included a spurt in capital expenditures. [SEI89, p. 106]

4. The federal government provides most of the support for university R&D (60% in 1989), but industry and funds from the universities themselves have been the fastest growing sources of support in the 1980s. [SEI89, p. 106]

5. Among federal agencies, the National Institutes of Health provide by far the largest share of support for university research (50%). NSF provides 24% and DOD 10%. [SEI89, p. 92] Over the years, NIH and NSF have both increased their shares of support, while other agencies have gradually moved out of the picture. NIH has expanded the most; its share of university R&D funding in 1969 was only 35%. [SEI89, p. 300-301]

6. The number of people engaged in university R&D has been growing much faster than the general workforce, but not as quickly as the workforce of scientists and engineers. Between 1977 and 1985, the general workforce increased 16%, the workforce of scientists and engineers 38%, and academic researchers 28%. [SEI89, p. 260, 262, 317]

7. Collaboration is on the increase in university research, in several directions. University researchers doubled their rate of collaboration across institutions and national boundaries between 1981 and 1986. The rate of cross-sectoral collaboration doubled between 1976 and 1986. [SEI89, 106]

8. The excellence of U.S. research remained steady through the 1970s and early 1980s, as indicated by citations from the world's literature. [SEI89, 343]

**Government Laboratories**

1. Overall, the federal government performs about a fourth of the R&D it supports in its own laboratories, primarily at the National Institutes of Health and in NASA, USDA, and DOD laboratories.

- Growth in these efforts has been modest in the 1980s as

compared with other sectors: 31% in constant dollars, as compared with 45% for industry and 56% for academic institutions. [SEI89, p. 91-92, 265]

- Even federal support for R&D grew fastest outside the federal laboratories in the 1980s--38% outside (in constant dollars), versus 30% in the federal laboratories. [SEI89, p. 276]

2. Federal laboratories perform about five times as much applied research and development as basic research. [SEI89, p. 92]

- Federal support for applied research (in all sectors) declined in the 1980s--about 9% overall (in constant dollars), but only 6% in the intramural laboratories.

- Federal development spending grew very quickly in the 1980s, though--49% overall, and 52% in federal intramural laboratories.

[SEI89, p. 276]

3. Obligations to Federally-funded Research and Development Centers (FFRDCs) is dominated by DOE and DOD. [SEI, p. 92-93]

**Contexts for R&D**

1. U.S. students are studying more science, but not grasping it as well as students from other countries. Time spent in science and mathematics courses in schools is up, but performance on international achievement tests is low by international standards. [SEI89, p. 20 and p. 8]

2. The U.S. public doesn't know (or doesn't believe) many facts that scientists consider elementary. But except in the area of views about human origins, they are no different in this regard than the publics of other nations. [SEI89, p. 17, 165-170]

3. Public attitudes toward science and technology as social forces are generally positive, but there is less confidence than there was in 1957 that science and technology will solve humanity's pressing problems. [SEI89, p. 171]

4. The public favors government funding for goal-directed programs over funding for basic research. In both 1972 and 1988, health and pollution control were high on the list of public priorities for research funds, and space and defense were low. [SEI89, p. 174 and SI72, p. 99]